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Returns to innovation: a structural treatment effect model of R&D subsidies

Tuomas Takalo
Bank of Finland

and

Tanja Tanayama
Helsinki School of Economics and HECER

and

Otto Toivanen
HECER

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HECER – Helsinki Center of Economic Research, P.O. Box 17 (Arkadiankatu 7), FI-00014 University of Helsinki, FINLAND, Tel +358-9-191-28780, Fax +358-9-191-28781, E-mail info-hecer@helsinki.fi, Internet www.hecer.fi

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Abstract

We study the returns to R&D, their distribution and their determinants, including the treatment effects of subsidies. We develop a model of continuous optimal treatment with outcome heterogeneity, where the treatment outcome depends on the applicant's investment. The model takes into account application costs, and isolates the effect of the treatment on the public agency running the treatment program. Under the assumption of a welfare-maximizing agency, we identify general equilibrium treatment effects and social returns to R&D. We take our model to project level data from the granting process of R&D subsidies and find that returns on R&D are high, their distribution skew, and treatment effect heterogeneity substantial. Agency's utility not appropriated by the applicant is linear in R&D. The median increase in this agency specific utility from subsidies is 44 000€. Ignoring application costs severely biases the estimated treatment effects and returns upwards.

JEL Classification: D21, D6, D73, H20, H83, L59, O30, O31

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Tanja Tanayama
HECER
P.O. Box 17
FI-00014 University of Helsinki
FINLAND
tanja.tanayama@helsinki.fi

Tuomas Takalo
Research Dept.
Bank of Finland
P.O. Box 160
FI-00101 Helsinki
FINLAND
tuomas.takalo@bof.fi

Otto Toivanen
HECER
P.O. Box 17
FI-00014 University of. Helsinki
FINLAND
otto.toivanen@helsinki.fi

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It has been long recognized that R&D and the distribution of benefits generated by it are crucial for economic growth. The endogenous growth literature has shown that markets typically provide too little R&D and has singled out subsidies to R&D as the main policy tool (e.g. Howitt 1999, Segerstrom 2000). Innovation ranks high on the policy agenda and R&D subsidies have become ubiquitous in practice, being one of the most important tools of innovation policy both in the U.S. and in many European countries.[1]

Some central questions concerning R&D and innovation policy remain however open. For example, our understanding of the social returns to innovation is still limited, nor is there much evidence on the joint distribution of private and social returns to R&D. Little is known on how spillovers are related to the level of R&D at project level. Further, we know surprisingly little about the programs that allocate R&D subsidies. How do the public agencies running programs decide subsidy levels? How do potential applicants decide whether or not to apply? What are the agencies' and the applicants' costs and benefits from the program, and how are they determined? In other words, what are the treatment effects of such a program, and their determinants? To answer these questions we build and estimate a structural model founded on the well-established treatment effects literature and the recent advances in structural industrial organization. Our empirical application uses detailed project level data on R&D investment plans and project characteristics, and R&D subsidy decisions by a government agency.

Methodologically we draw on the extensive treatment effects and labor supply literatures (see e.g. Heckman, LaLonde, and Smith 1999, Blundell and Costa-Dias 2002

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[1] R&D subsidies are the second largest and fastest growing form of industrial aid in developed countries (Nevo 1998); the U.S. has had several programs (Lerner 1999) and currently spends $1.5 billion a year on one R&D subsidy program alone (the SBIR; see http://www.sba.gov/sbir/indexwhatwedo.html, visited on January 21, 2004) and the EU exempts R&D subsidies from its state aid rules. In Finland where our data originates, R&D subsidies are the most important tool of innovation policy (Georghiu et al. 2003).

and Blundell and MaCurdy 1999 for surveys)[2] and on structural industrial organization work (surveyed by e.g. Reiss and Wolak, 2004).[3] While our objective is to construct and estimate a structural model of the application and selection process into a voluntary treatment program, the institutional setting in our data differs considerably from those usually encountered in the treatment effects literature. As a result, our model contains several ingredients not commonly embedded in the structural treatment effects literature. We model a continuous, optimal treatment with outcome heterogeneity. In our model the treatment outcome is a function of the applicant's investment, which in turn is a function of the received treatment. The model takes into account application costs, and isolates the effects of the treatment that are specific to the agency. Under the assumption of a benevolent public agency, our model identifies general equilibrium treatment effects and social returns to R&D. A key benefit of the structural approach is that the model yields economic interpretation of the unobserved (to the econometrician) shocks and all the estimated parameters. Given our parameterization of the model, it also yields estimation equations that resemble those traditionally used in e.g. the returns to education literature.

Our empirical application relates to the extensive literatures on innovation and the effects R&D subsidies. The existing empirical research has produced indisputable insights into the effects of R&D and R&D subsidies but, in many cases, advances have

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[2] The papers in the treatment program literature having a close relation to ours include Bjorklund and Moffitt (1987), Heckman and Robb (1985), Maddala (1983, ch. 9), Manski (2000), and Heckman and Smith (2004) who stress the application and selection decisions, as well as Keane and Wolpin (2001) and Cameron and Taber (2004) who evaluate the effects of tuition subsidies and borrowing constraints. Our paper has a link with the literature on revealed bureaucrat preferences such as McFadden (1975, 1976) who examines bureaucratic decision making in freeway route selection and Heckman, Smith and Taber (1996) who study how the objectives of the office holders affect the selection decisions. Dehejia (2005), like us, models the selection decisions of the public agency. Willis and Rosen's (1979) contribution on education is also in many ways close to our paper. Although the literature on continuous treatment effects and general equilibrium effects is sparse, Heckman (1997) provides theoretical insights in the modeling of continuous treatment effects and Imbens (2000) and Lechner (2001) generalize the standard discrete zero-one treatment model to multiple treatment levels. Heckman, Lochner and Taber (1998) and Davidson and Woodbury (1993) in turn suggest procedures to identify general equilibrium treatment effects.

[3] In the structural industrial organization literature, Wolak (1994) and Gagnepain and Ivaldi (2002) are close to ours methodologically.

been hampered by lack of sufficient data. For example, the established but unsettled literature on the R&D-size relationship (see e.g. Cohen 1995) relies almost exclusively on firm level data. The literature on the effects of R&D subsidies is diverse, and methodologically mostly distinct from our approach (see David, Hall, and Toole 2000, and Klette, Møen and Griliches 2000, for surveys). The only paper we know that studies the granting and application side of R&D subsidies is Blanes and Busom (2004). They estimate reduced form models of the joint application and granting decision. Their main finding that firms even in the same industry have different application thresholds both within and between the agencies supports our model and results. Wallsten (2000) and Gonzaléz, Jaumandreau, and Pazó (2005) are rare exceptions in taking a more structural approach to modeling the effects of R&D subsidies. Structural modeling is, however, used more extensively in many other areas of innovation research.[4]

We have access to rich data from Tekes (the National Technology Agency of Finland), the sole source of R&D subsidies in Finland. Finland provides a neat case for our study because i) innovation policy has long been a central theme in government policy, ii) partly because of successful policy, Finland has particularly rapidly transformed to a technology intensive economy (see e.g. Trajtenberg 2001), and iii) subsidies and, as a result, Tekes, constitute the main innovation policy tool. For example, there are no R&D tax benefits that could jeopardize the policy analysis. The data contain all the subsidy applications, the agency's internal ratings of the applications and its decisions over a two- and half-year period (Jan. 2000 – June 2002). The information on

[4]See, e.g. Pakes (1986) on patent value, Levin and Reiss (1988) on cost-reducing and demand creating R&D, Lanjouw (1998) on patent value and litigation, Eaton and Kortum (2002) on the role of trade in diffusing the benefits of new technology, Jovanovic and Eeckhout (2002) on the impact of technological spillovers on the firm size distribution, and Petrin (2002) on the welfare effects of new products.

applications is matched to data on over 14 000 Finnish firms that constitute a large proportion of potential applicants.

We find that the returns appropriated by the agency but not by the firm are linear in R&D expenditures and positive in expectation for 97% of the firms in our sample. Private returns are very high and their distribution skew, following earlier findings at least since Griliches (1958). Non-applicants' projects generate larger returns on investments, but applicants' and non-applicants' projects generate similar joint rates of return on the subsidy program, defined as the sum of the applicants' and agency's returns divided by the cost of subsidies. We also identify new treatment effects by measuring the effect of treatments on the agency, and by taking into account application costs. We find considerable heterogeneity in all treatment effects. Neglecting application costs causes a significant upward bias. In allocating the subsidies, the agency generally adheres to the publicly announced principles.

In Section II we present our model. We explain the institutional background and data in Section III and statistical assumptions, identification and estimation in Section IV. Econometric results are reported in Section V and implications of the model in Section VI. Conclusions are in Section VII.

II. The model

Our empirical application resembles what Jaffe (2002) calls a 'canonical' research grant program: There is a pool of firms (potential applicants) who have R&D projects that require costly investments. The firms decide whether or not to apply for a subsidy (treatment) program. A subsidy, if received, lowers the marginal cost of their investment. The program is run by a public agency whose objective function includes the firms' utility as an argument. The agency screens and evaluates the project proposals and then decides how large subsidy (treatment), if any, to give to each actual applicant. Finally, all firms – those that did not apply for a subsidy, those that did but were rejected and the applicants that received a subsidy - maximize profits by choosing their R&D investments.[5]

We model the subsidy program as a four-stage game of incomplete information between a firm (a potential applicant) and the agency. In stage zero, the players' types are determined. The agency has a three-dimensional type, $t_A = (\eta\ ,\omega_c,\omega_m) \in \Re^3$, drawn from a common knowledge joint (normal) distribution and each firm has a two-dimensional type, $t_F = (\varepsilon, v_0) \in \Re^2$, drawn from a common knowledge bivariate (normal) distribution. The type of a player contributes to the player's valuation of a project. As will be made more precise below, both players' valuations embody idiosyncratic shocks that constitute the types. Conditional on publicly observed information the shocks are independently distributed. In stage one, the firm decides whether or not to apply to the subsidy program. The application includes a proposal for an R&D project. In stage two, the agency screens and evaluates the proposed project. It then decides the level of subsidy, *s*, which is the share of the investment cost covered by the agency. The subsidy level can be subject to a maximum constraint, $\bar{s}$, and the level is zero if there is no application or the application is rejected, so that $s \in [0, \bar{s}\,]$, $\bar{s} \leq 1$. In stage three, the firm makes the R&D investment, *R*, $R \in [0, \infty)$, with or without the subsidy.

Our model builds on the following assumptions:

A.1. The potential applicant is uncertain about the agency's valuation of her project.

[5] Our model could also deal with some other treatment program than an R&D subsidy program. For example, one can think of expected employment being a project and a free or subsidized participation in an educational program being a treatment. Those who do not receive the treatment can also often participate in educational programs such as JTPA but for a full price (see e.g. Heckman and Smith, 1995), so the treatment effectively reduces the cost of educational investment. The situation we model is also close to the one in Roberts, Maddala and Enholm (1978) who study what determines whether a regulated firm requests a review of its regulated rate of return.

A.2. A subsidy cannot be misused.

A.3. There are no constraints on the firm's investment.

A.4. The agency's budget constraint does not bind.

A.5. The firm's investment is non-contractible.

A.6. All potential general equilibrium effects are captured by the agency's objective function.

A.1 ensures that (in line with our data) equilibrium outcomes where a firm applies for a subsidy only to be turned down are possible. It accommodates various informational assumptions concerning the players' types. It, for example, makes no difference whether the firm's type is private information or common knowledge: it turns out that due to our functional form assumptions (see equations (1) and (5) below), the firm can neither signal its type nor does the agency care about it. For clarity, we assume that the firm's type is common knowledge.[6]

It is also immaterial whether the agency's type is private information or the potential applicant and the agency operate under symmetric but incomplete information regarding the agency's type. We only need to assume that the firm, when contemplating application, does not exactly know how the agency values her project. For brevity, we assume that the agency learns its type exactly after screening (i.e. symmetric but incomplete information regarding the agency's type prevails in the application stage).[7]

[6] In an earlier version (HECER DP no. 76/2005) we develop a treatment program model with general functional forms. There we need to assume that the firm's type is common knowledge to rule out signalling. That is, with more general functional forms we need to make more restrictive informational assumptions.

[7] Alternatively, we could assume that the applicant has private information about the agency's returns to its project and that the agency receives a noisy signal upon it after screening the project. Since the applicant could not credibly signal its private information in our model, this assumption would yield the same optimal application and subsidy decisions as the (more realistic) assumption we use.

A.2 excludes moral hazard problems in the use of a treatment.[8] By A.3, the solution to the applicant's maximization problem in the last stage is interior. This assumption rules out credit rationing and ensures that a firm's project is executed even if the firm does not apply for a subsidy or the application is rejected.[9] A.4 is motivated by simplicity, but we do impose a cost of financing on the agency. A.5 is more realistic, since it prevents the firm and the agency from writing a binding contract specifying the amount the firm invests conditional on the subsidy it receives. A.6 is a weaker form of the standard, heavily criticized (e.g. Heckman, Lochner and Taber, 1998), assumption in the treatment literature that ignores general equilibrium effects. In principle the agency should be a benevolent social planner that takes into account all effects of the treatment. If this is the case, our model will identify general equilibrium treatment effects.

We focus on perfect Bayesian equilibria where, in stage one, a potential applicant correctly anticipates the type-contingent strategies of the agency in stage two, and where the firm's and agency's strategies are sequentially rational. In this extensive form game the firm's posterior belief concerning the agency's type after receiving a subsidy is inconsequential, so we start from the firm's maximization problem in stage three.

A. Objective function of the firm and stage three of the game

We specify firm *i*'s objective function as

$$(1) \qquad \Pi(R_i, s_i, X_i, \varepsilon_i) = \pi_i + \exp(X_i\beta + \varepsilon_i)\ln R_i - (1 - s_i)R_i\,,$$

[8] In practice, moral hazard temptations are certainly pervasive with monetary treatments, as in our case. As a result, Tekes has several safe-guards against expropriation. For example, subsidies are only paid against receipts, there is a euro limit to a subsidy, and a significant number of subsidized R&D projects is annually randomly audited. Because the safe-guards are common knowledge, and the misuses found in the audits or otherwise are rare, we think that the assumption depicts equilibrium behavior.

[9] Although financial market failure has traditionally been a rationale for R&D subsidies, the revealed motivations for R&D subsidies have become increasingly spillover-oriented. A study using Finnish data (Hyytinen and Pajarinen 2003), and an evaluation of Finnish innovation policy (Georghiu et al. 2003) conclude that only small, R&D intensive, growth-oriented firms may face financial constraints. The situation is similar in many other industrialized countries, as the survey by Hall (2002) confirms. The decline of the financial constraint motivation for R&D subsidies is also reflected in our application: although Tekes also grants low-interest loans, most firms were not interested in them.

where s_i is the subsidy (treatment), R_i is the R&D investment, X_i is a vector of observable firm characteristics, and β a vector of parameters to be estimated. The marginal profitability is also affected by a random shock, ε_i, (i.e. the (other dimension of) firm *i's* type). The random shock ε_i is distributed by nature, uncorrelated with the observable firm characteristics, observed by the firm, and unobserved by the econometrician. As explained above, it may or may not be observable to the agency. The reservation value including other projects is embodied in π_i.[10]

In stage three, the firm chooses its investment R_i to maximize (1). Since the objective function is concave in R_i, the first-order condition

$$(2) \qquad R_i = \frac{\exp(X_i\beta + \varepsilon_i)}{1 - s_i}$$

gives the firm's optimal investment $R_i(s_i)$ as an increasing function of the subsidy level. Equations (1) and (2) show the economic interpretation of ε_i: a positive shock to the marginal profitability leads to a larger investment. An optimal investment given by (2) could in theory decrease profits but, in such a case, the firm would not invest at all, and consequently would not apply for a subsidy.

B. Agency utility and stage two of the game

The agency's utility from applicant *i*'s project is given by

$$(3) \qquad U(R_i(s_i), s_i, X_i, Z_i, \varepsilon_i, \eta_i) = V(Z_i, \eta_i, R_i(s_i)) + \Pi(X_i, R_i(s_i), s_i, \varepsilon_i) - gs_iR_i(s_i) - F_i,$$

where F_i is the sum of the fixed costs of applying and processing the application, g is the constant opportunity cost of the agency's resources, e.g. the opportunity cost of tax funds. As (3) shows, the firm's utility (1) directly enters the agency's utility function.

[10] We could also generalize (1) to multiple projects. For each firm with multiple project applications, we could treat each project as a separate observation. If the project-specific unobservables are uncorrelated, this will not materially affect estimation. The interpretation for non-applicants would be that none of their projects resulted in an application.

The interpretation of *V*( ) is fundamental to our analysis. It captures the agency specific returns from the project. That is, *V*( ) captures the effects of the firm's project on the agency beyond the firm's utility and the direct costs of subsidy and the application process. In our empirical application, *V*( ) can include externalities from a firm's R&D such as consumer surplus or spillovers to other firms. At the level of an individual decision maker *V*( ) could also consist of idiosyncratic benefits from giving a subsidy such as direct (ex post) bribes or indirect ones, e.g. through a revolving door mechanism. The agency specific utility (*V*( )) can also be negative or decreasing in the investment level. For example, it is possible that some R&D projects exhibit negative externalities while being privately profitable.

In *V*( ), Z_i is a vector of observable firm characteristics, which contains the same elements as X_i. In our case, Z_i includes also the two screening outcomes (discussed next) that are observed by the agency and by the econometrician but not by the firm, i.e. that are not part of X_i. Note that *V*( ) includes also η_i, which constitutes part of the agency's type, defined as a random shock to the agency specific utility from project *i*. The shock is assumed to be distributed by nature, uncorrelated with firm characteristics, and unobserved by the econometrician. By A.1, η_i is also unobserved by the potential applicant and observed by the agency (at the latest) after application and screening takes place. In other words, A.1 means that the potential applicant is uncertain about how the agency, after screening the project proposal, sees the project and its potential to generate spillovers, consumer surplus, or private benefits to the agency's civil servants.

We assume that when deriving the optimal subsidy the agency screens - in line with reality - the application and learns, besides η_i, the two elements of Z_i that are not in X_i. The screening results in two grades on a Likert scale of 5 and we assume this to be common knowledge. The resulting 25 grade combinations are modeled by a latent regression framework. Denoting the latent value of grading dimension $j\in\{c,\ m\}$ for application i by w_{ij}^* and the observed value by w_{ij}, we get:

$$w_{ij} = h \text{ if } \mu_{h-1} < w_{ij}^* = T_i\zeta_j + \omega_{ij} \le \mu_h$$

(4) $$h = 1,\ldots,5,\ \mu_0 \to -\infty,\ \mu_1 = 1, \mu_2 = 2,\ldots, \mu_5 \to \infty$$

$$\omega_{ij} \sim \mathrm{N}(0,\ 1)\ \ j\in\{c,\ m\},\ \mathrm{cov}(\omega_{ic}, \omega_{im}) = 0,$$

where T_i is a vector of observable firm characteristics and ζ_j is parameter vector to be estimated. We assume that the unobservables ω_{ij}, which are part of the agency's type, are normally distributed and uncorrelated both with each other and other unobservables of the model. Equation (4) produces probabilities p_t^c and p_k^m of getting grades t and k in the two grading dimensions c and m (which stand for technological challenge and market risk, see the next section). In other words, p_t^c and p_k^m reflect the firm's beliefs about the agency's valuation in dimensions ω_c and ω_m.

In stage two, the agency chooses a subsidy level s_i, $s \in [0, \bar{s}]$ where $\bar{s} \le 1$, to maximize its expected discounted utility from project i, taking (2) into account. To arrive at an estimable model we need to specify the effect of R_i on $V(\ )$. We assume that

(5) $\partial V / \partial R_i = Z_i\delta + \eta_i$,

where δ is a vector of parameters to be estimated. An implication of (5) is that $V(\ )$ is proportional to R&D investment. This may be unrealistic but similar assumptions are common in the literature on growth and R&D spillovers. We test this assumption below and do not reject it.

By using the envelope theorem, (1), (2) and (5), the first-order condition for the agency's unconstrained problem can be written as

(6) $s_i = 1 - g + Z_i\delta + \eta_i$.

We proceed under the assumption that (6) characterizes the maximum and verify later in the proof of the Proposition that this indeed is the case. Equation (6) shows how the agency's unconstrained decision rule is decreasing in the shadow cost of public funds, g. It is independent of the firm's type, ε_i, so that even if the agency did not know the private shock to the marginal profitability of R&D, it would not matter. The optimal subsidy depends positively on the shock to the agency specific utility, η_i. The minimum constraint of s=0 binds for $\eta_i \leq \underline{\eta}_i \equiv g\text{-}1\text{-}Z_i\delta$ and the maximum constraint of $\bar{s}$ for $\eta_i \geq \overline{\eta}_i \equiv \bar{s} + g\text{-}1\text{-}Z_i\delta$.

C. Stage one of the game: to apply or not

In stage one, a profit maximizing firm applies for a subsidy if the expected utility from applying is at least as large as that from not applying. To calculate the benefits from applying, the firm needs to calculate the expected profits given all the possible valuations of the agency. To do this, the firm has to calculate the probabilities for a submitted application to get particular grades in the two evaluation dimensions and the expected valuation of the agency over all possible η_i. Let $\phi(\eta_i)$ define firm i's belief about the agency's type in dimension η and let $\Phi(\eta_i)$ be the corresponding cumulative distribution function. The next step is to calculate what will be the subsidy level associated with each possible valuation.

The firm weights the costs of applying against the profit increase stemming from these expected subsidies. We specify the application costs as

(7) $\quad K_i = \exp(Y_i\theta + v_i)$

where Y_i is a vector of observable firm characteristics, θ is a vector of parameters to be estimated and v_i is a random cost shock (the other part of the firm's type), distributed by nature, uncorrelated with observable firm characteristics, observed by the firm, and unobserved by the econometrician and the agency (again, the latter is immaterial).

Dropping the subscript i the applicant's decision rule can be written as

$$\text{(8)} \quad \sum_{t=1}^{5}\sum_{k=1}^{5} p_t^c p_k^m \{\Phi(\underline{\eta})\Pi(R(0),0) + \int_{\underline{\eta}}^{\overline{\eta}} \Pi(R(s(t,k,\eta)), s(t,k,\eta))\phi(\eta)d\eta + [1-\Phi(\overline{\eta})]\Pi(R(\overline{s}),\overline{s})\} \geq K + \Pi(R(0),0) .$$

The costs of applying are on the right hand side of (8). Besides the fixed costs, the firm takes into account that it can execute the project without a subsidy (A.3), in which case the project yields $\Pi(R_i(0),0)$. The expected benefits of applying are on the left hand side where the summation is over the potential screening outcomes. The first term in the curly brackets is the expected profit in case the application is rejected. The rejection occurs when $\eta_i \leq \underline{\eta}_i$, i.e. with probability $\Phi(\underline{\eta}_i \equiv g\text{-}1\text{-}Z_i\delta)$. The second term is the expected profit when $\eta_i \in (\underline{\eta}_i, \overline{\eta}_i)$ in which case the firm receives the optimal interior subsidy given by (6). The third term is the probability of receiving a maximal subsidy multiplied by the profits with the maximal subsidy. This case occurs with probability $1-\Phi(\overline{\eta}_i \equiv \overline{s} + g - 1 - Z_i\delta)$.

D. Equilibrium of the game

We complete the model by showing that there is a unique Perfect Bayesian equilibrium. This ensures a meaningful econometric implementation of the model. Perfect Baysian equilibria in our model consist of four components: 1) A firm's decision whether to apply for a subsidy or not. Let $d_i \in \{0,1\}$ denote firm i's application decision where d_i=1 if the firm applies for a subsidy and d_i=0 if the firm does not apply. 2) The firm's belief functions $p_t^c(d_i)$, $p_k^m(d_i)$ and $\phi(\eta_i, d_i)$ that describe a (common) assessment of how the agency values the firm's project given d_i. 3) The agency's subsidy decision

$s_i*(\eta_i,t_i,k_i,d_i)$ which determines the level of subsidy granted to firm *i* given d_i and the information revealed in the screening process. 4) The firm's optimal investment $R_i*(s_i,d_i)$ given s_i and d_i.

PROPOSITION. There is a unique Perfect Bayesian equilibrium where d_i=1 if (8) holds, $s_i*(\eta_i,t_i,k_i,d_i)$ is zero for $\eta_i \leq \underline{\eta}_i$, is given by (6) for $\eta_i \in (\underline{\eta}_i, \overline{\eta}_i)$ and is $\bar{s}$ for $\eta_i \geq \overline{\eta}_i$, and $R_i*(s_i,d_i)$ is given by (2).

Proof: For brevity of notation, we drop the subscript *i* and the arguments *t*, *k*, *d*. In stage three, the firm has a well-defined best-reply function $R*(s)$ given by (2). In stage two, the agency maximizes its expected utility conditional on its type. There is a unique type-contingent optimal subsidy if the second order condition for the agency's decision problem holds. Since we have linear constrains of minimum and maximum subsidies, it suffices to show that $U(R*(s),s)$ is concave when evaluated at the interior solution given by (6). Differentiating (3) twice shows that $U(R*(s),s)$ is concave if

$$(9)\qquad \left(\frac{dR}{ds}\right)^2\left(\frac{\partial^2 V}{\partial R^2}+\frac{\partial^2 \Pi}{\partial R^2}\right)+2\frac{dR}{ds}\left(\frac{\partial^2 \Pi}{\partial R \partial s}-g\right)+\frac{d^2R}{ds^2}\left(\frac{\partial \Pi}{\partial R}+\frac{\partial V}{\partial R}-gs\right)+\frac{\partial^2 \Pi}{\partial s^2}<0.$$

From (1) and (4) we see that $\partial^2 V/\partial R^2$ and $\partial^2\Pi/\partial s^2$ are zero. Together with the envelope theorem ($\partial\Pi/\partial R$=0) they imply that (9) can be simplified to $\left(\frac{dR}{ds}\right)^2\frac{\partial^2 \Pi}{\partial R^2}+2\frac{dR}{ds}\left(\frac{\partial^2 \Pi}{\partial R \partial s}-g\right)+\frac{d^2R}{ds^2}\left(\frac{\partial V}{\partial R}-gs\right)<0$. Using (2) and (5) we get $-\left(\frac{R}{1-s}\right)^2\left(\frac{\exp(X\beta+\varepsilon)}{R^2}\right)+\frac{2R}{1-s}(1-g)+\frac{2R}{(1-s)^2}(Z\delta+\eta-gs)<0$, which using (2) further simplifies to $\frac{R}{1-s}\left[-1+2(1-g)+\frac{2(Z\delta+\eta-gs)}{1-s}\right]<0$. Evaluating this expression at the interior solution given by (6) yields s-1<0. Consequently, there is a unique maximum that solves the agency's decision problem. Because the optimal unconstrained subsidy (6) is increasing in η, $s^*(\eta)=0$ for $\eta \leq \underline{\eta}$, $s^*(\eta)$ is given by (6) for $\eta \in (\underline{\eta}, \overline{\eta})$ and $s^*(\eta)=\overline{s}$ for $\eta \geq \overline{\eta}$. Thus, the optimal type-contingent action of the agency in stage two is unique. In stage one the firm decides whether to apply or not given $s^*(\eta)$ and p_t^c, p_k^m and $\phi(\eta)$. Since in a Perfect Bayesian Equilibrium the firm's belief must be consistent with the agency's strategy, $d_i=1$ if (8) holds. Clearly, the agency's best response to $d=1$ is $s^*(\eta)$ so we have found a Perfect Bayesian equilibrium. Since the utility maximizing action in each stage of the game is unique, the equilibrium is also unique. ■

III. Finnish innovation policy, Tekes and data[11]

A. Innovation policy and Tekes

In 2001 Finland invested 3.6 per cent of GDP – 5 billion euros - on R&D. Tekes is the principal public financier of private R&D in Finland.[12] The primary objective of Tekes is to promote the competitiveness of Finnish industry and the service sector by providing funding and advice to both business and public R&D. To achieve these goals, Tekes strives to increase Finnish firms' R&D and risk-taking. Tekes is also responsible for allocating funding from European Regional Development Funds (ERDF). Funding from ERDF is subject to the general funding criteria of Tekes, but it is meant for least-favored regions. As a result, Tekes funding has also a regional dimension through ERDF. Finnish regions differ greatly in their socio-economic characters, economic performance, and

[11] As our application data is from Jan. 2000- June 2002, we use 2001 figures to describe the environment. One of us spent nine months in Tekes to get acquainted with the actual decision making process. Among other things she participated in the decision making meetings. Public information about Tekes can be found at http://www.tekes.fi/eng/, accessed December 20th, 2004.

[12] Main public funding organizations in the Finnish innovation system in addition to Tekes are the Academy of Finland, Employment and Economic Development Centers (T&E Centers), Finnvera, Industry Investment and Sitra. Also the Foundation of Finnish Inventions (Innofin) provides financial support for innovation. See Georghiu et al. (2003) for a recent description and evaluation of the Finnish innovation policy institutions.

their R&D-intensity, e.g. some 20% of the population lives in the capital region in Southern Finland where also a large part of the economic activity and most of R&D takes place.

Besides funding business R&D, Tekes finances feasibility studies, and R&D by public sector including scientific research. In 2001 Tekes funding amounted to 387 million euros, and it received 2948 applications of which almost exactly 2/3 were accepted. The number of applications by the business sector for R&D funding was 1357 and, again, 2/3 of them were accepted. In monetary terms, the business sector applied for 526 million euros while 211 million euros were granted to it.

Business R&D funding consists of grants, low-interest loans and capital loans. Tekes' low-interest loans not only have an interest rate below the market rate but they are also soft: If the project turns out to be a commercial failure, the loan may not have to be paid back. A capital loan granted by Tekes differs from the standard private sector debt contract in various ways: it is included in fixed assets in the balance sheet, it can be paid off only when unrestricted shareholders' equity is positive and the debtor cannot give collateral for the loan. The share of each instrument of the total funding allocated to business R&D in 2001 was 69 %, 18% and 13 %. Subsidy applications covered 83 % of the amount applied whereas in terms of granted amount subsidies' share was 67%. The overlook of loans by applicants suggests that they do not encounter significant financial constrains, supporting our assumption A.4 (cf. footnote 9).

The application process from the submission to the final decision, which to our understanding is well known among potential applicants, proceeds along the lines of the theory model of Section II. There are two things worth mentioning: First, an application has to include the purpose and the budget of the R&D project for which Tekes funding is needed, and the applied amount of funding in euros. We utilize this below. Second, Tekes screens the application and grades it in several dimensions using a 6-point Likert scale from 0-5, not two, as we assume for simplicity. However, according to Tekes' civil servants, the most important dimensions in project evaluation concern the technological challenge of the project and its market risk which are the dimensions we include.[13] Tekes' public decision criteria are: The project's effect on the competitiveness of the applicant, the technology to be developed, the resources reserved for the project, the collaboration with other firms within the project, societal benefits, and the effect of Tekes' funding. Tekes takes into account whether the application comes from an SME and, as mentioned above, it also has a regional dimension through ERDF.

Tekes' final decision is based on the proposed budget of the project before the R&D investments are made, but the actual funding is only given ex post against the incurred costs. Decision making is constrained by the rules preventing negative subsidies and very large subsidies both in relative and absolute terms. In other words, a subsidy is granted ex ante as a share of to-be-incurred R&D costs. There is an upper bound for this share: If the firm fulfils the EU SME criterion, the upper bound is 0.6, otherwise 0.5.[14] The actual funding then covers the promised share of incurred costs up to a specified euro limit. The limit should allow the promised reimbursement of investment costs up to the profit maximizing level but prevent Tekes from covering costs extraneous to the project

[13] A loose translation of grades of technological challenge is 0 = 'no technical challenge', 1 = 'technological novelty only for the applicant', 2 =' technological novelty for the network or the region', 3 = 'national state-of-the-art', 4 = 'demanding international level', and 5 = ' international state-of-the-art'. For market risk, it is 0 = 'no identifiable risk', 1 = 'small risk', 2 = 'considerable risk', 3 = 'big risk', 4 = 'very big risk', and 5 = 'unbearable risk'.

[14] Given our data, it is unlikely that firms deliberately keep themselves below the EU SME boundary requiring that a firm has less than 250 employees and has either sales less than 40 million euros or the balance sheet less than 27 million euros. Most of the firms in our data are well below the boundary, as 95% them have less than 110 employees, less than 14 million euros in sales, and a balance sheet of less than 11 million. As the SME criterion also maintains that large firms can hold at most 25% of a SME's equity and votes, it is unlikely that many of the SMEs are subsidiaries of large firms. We thus consider the SME status of a firm exogenous.

proposal.[15] In terms of our model, these practices amount to $\underline{s}=0$, $\bar{s}\in\{0.5,0.6\}$ and a goal of setting the euro limit at $sR(s)$.

Tekes also sometimes adjusts a proposed budget, both down and up, when an applicant, e.g. applies subsidies for costs that Tekes cannot cover. In practice an upward adjustment is rare and in principle occurs only if a project significantly changes character during the application process. Such upgrades can thus be taken as exogenous events that cannot be manipulated by Tekes to overcome the institutional limits on its subsidy allocation.

B. Data

Our data come from two sources. The project level data come from Tekes, containing all applications to Tekes from January 1st 2000 to June 30th 2002. They consist of detailed information on the project proposals and Tekes' decisions. The firm level data covering originally 14 657 Finnish firms come from Asiakastieto Ltd, which is a for-profit company collecting, standardizing, and selling firm specific quantitative information.[16] Asiakastieto's data are based on public registers and on information collected by Asiakastieto itself. The data contain for example, firms' official profit sheet and balance sheet statements, and include all the firms who file their data in the public register or submit the information to Asiakastieto. We use the 1999 cross section, i.e. all firm characteristics are recorded earlier than the application data. The sample was drawn from Asiakastieto's registers in 2002 according to three criteria: i) the most recent financial statement of the firm in the register is either from 2000 or 2001; ii) the firm is a

[15] As mentioned in footnote 8, the euro limit alleviates the moral hazard problem. There are also other reasons for the limit. Because Tekes has an annual operating budget, a practical decision rule is to cap the euro amount using the proposed budget, as it is the best available information at the time the subsidy decision is made. Tekes is also monitored both by the press and politicians. Tekes civil servants may want avoid the accusations of granting larger subsidies than originally planned. At the same time, however, there may be a desire to make the limit high enough to allow profit maximizing behavior of applicants.

[16] More information about Asiakastieto can be found at http://www.asiakastieto.fi/en/, accessed June 20th, 2005.

corporation; and iii) the industrial classification of the firm is manufacturing, ICT, research and development, architectural and engineering and related technical consultancy, or technical testing and analysis. Firms in these industries are most likely to apply for funding from Tekes. After cleaning the data of firms with missing values, we are left with 10 944 firms. These firms form a large proportion of the population of potential applicants, and they constitute our sample of potential applicants.

Some 1000 firms from outside our sample filed applications to Tekes during the observation period. There are three principal reasons for the exclusion of an applicant from our sample: 1) the firm did not exist in 1999; 2) the firm did not operate in the industries from which the sample was formed; and 3) the firm was so small that it was not obliged by law to send its balance and profit sheets to the official registry.

The data we use in the estimations comprises 915 applications, where we have limited the count to one per firm by using the first application by each firm within our observation period. [17] 722 of these applications were accepted, i.e. received a positive subsidy share. Table 1 displays summary statistics of our explanatory variables for potential applicants, and Table 2 conditions the statistics on the application decision and success. As Table 1 shows, potential applicants are heterogenous. They are on average 12 years old with 35 employees. A very high proportion are SMEs according to the official EU standard (cf. footnote 14). As explained, the SME criterion determines the upper bound of the share of the R&D costs covered by Tekes, and we therefore need to take it into account in our estimations. Sales per employee, a measure of value added, is 165 000 euros. Some 6% are exporters. [18]

[17] Several firms in our data had multiple applications during our observation period. The firms in our sample account for roughly half of all applications.

[18] The figure excludes firms with both exports and imports. We have repeated our estimations by including in the "exporter" category all firms that report exports regardless of whether they report imports or not. The results are qualitatively identical, and quantitatively close to those reported.

[TABLE 1 HERE]

We also have information on two corporate governance variables. In some 14% of potential applicants, the CEO is also the chairman of the board. Such an arrangement can, on the one hand, improve the information flow between the board and the executive but, on the other hand, weakens the board's independence. The board of an average potential applicant has four to five members. A larger board is costlier but is more likely to include members with outside knowledge that may be useful either in conducting R&D (e.g. choosing among competing projects, organizing management of current projects, monitoring), or in the application process itself.

From Table 2 we see that applicants are larger than non-applicants and successful applicants larger than rejected ones. The median number of employees for non-applicants is 5, for applicants 26, and for rejected applicants 21. The applicants also tend to have larger boards. Quite naturally, applicants have more previous applications on average than non-applicants. The difference in both means and medians is 4.

Table 3 reports information about applications and Tekes' decisions. Some 21% of applications are rejected. The proposed projects involve on average an investment of 630 000 euros; the rejected proposals are clearly smaller with a mean of 385 000 euros. According to Tekes' rating, the projects have on average a technical challenge of 2 (scale 0-5), and rejected proposals have on average a lower score of 1.5. The mean risk score is also 2, and it is the same for successful and rejected applications (see the Appendix for more information).

[TABLE 2 HERE]

As explained, Tekes grants low-interest and capital loans besides subsidies. Because it is hard to calculate the value of such non-standard loans to the applicants, we pool the instruments. We thus define the subsidy per cent as the sum of all three forms of financing, divided by accepted proposed investment. As some 60% of applicants only apply for a subsidy, and over 80% are only granted a subsidy, this seems a reasonable simplification. Measuring a subsidy in this way, 0.4% of applicants get the maximum subsidy.[19] Successful applicants receive on average a subsidy that covers 32% of the R&D investment costs. We test the robustness of our results to the definition of a subsidy by using only pure subsidies as the dependent variable in the Tekes decision rule.

[TABLE 3 HERE]

IV. The econometric model

A. The model

We now operationalize the model presented in Section II. Using (1), (2) and (7), and taking logarithms on both sides, the application rule can be derived from (8) (again, subscript *i* omitted) as

(10) $$d = 1\left[X\beta - Y\theta + \ln \sum_{t=1}^{5} \sum_{k=1}^{5} p_t^c p_k^m \left\{ \int_{\underline{\eta}}^{\overline{\eta}} -\ln\left(1 - s(t,k,\eta)\right)\phi(\eta)d\eta - \left(1 - \Phi(\overline{\eta})\right)\ln(1-\overline{s}) \right\} \geq \nu - \varepsilon \right].$$ [20]

In words, the application rule is given by an indicator function d_i that takes the value one if firm *i* finds it profitable to apply for a subsidy. The investment equation can then be rewritten, upon taking logarithms of (2), as

(11) $$\ln R_i^*(s_i) = X_i\,\beta - \ln(1-s_i) + \varepsilon_i\,,$$

with observation $\ln R_i = d_i \ln R_i^*$ and the agency decision rule (6) as

(12) $$s_i^* = (1-g) + Z_i\,\delta + \eta_i\,,$$

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[19] There is a cluster of firms right below the maximum subsidy: 1.9% of applicants get a subsidy which is less than one percentage point below the maximum subsidy, and 2.5% get a subsidy less than 5 percentage points below the maximum. At the lower end there is no such clustering: on the contrary, no firm gets a subsidy that is less than 2.9%: however, 2.6% of applicants get a subsidy that is greater than 2.9% and less than 5% .

[20] Note that we can take logarithms on the inequality since the term $\sum_{t=1}^{5}\sum_{k=1}^{5} p_t^c p_k^m \left\{ \int_{\underline{\eta}}^{\overline{\eta}} -\ln\left(1 - s(t,k,\eta)\right)\phi(\eta)d\eta - \left(1-\Phi(\overline{\eta})\right)\ln(1-\overline{s}) \right\}$ is always greater than zero.

with observations $d_i s_i = 0$ if $s_i^* \leq 0$ and $d_i s_i = \bar{s}$ if $s_i^* \geq \bar{s}$. Our econometric model can thus be summarized by *the screening equations (4), the application equation (10), the investment equation* (11) and *the Tekes decision rule* (12).

B. Statistical assumptions, identification and estimation

We now explain our statistical assumptions, how identification takes place, and how we estimate the model. Our econometric model contains five unobservables, ω_j, ε, η and ν. They are assumed to be uncorrelated with the observed applicant characteristics. Estimating the model without imposing restrictions on the covariation of the unobservables is in principle possible by using a simulation estimator. However, assuming that η is uncorrelated with ε and ν_0 yields a large reduction in computational cost, because then the Tekes decision rule (12) is no longer subject to a selection problem. This means that estimation can be broken into three steps. Since our tests (see below) indicate that we cannot reject the Null hypothesis of no correlation between $\varepsilon - \nu$ and η, in estimating the model by (pseudo-) ML, we impose

A.7 a) $\nu = (1+\rho)\varepsilon + \nu_0$, b) $\eta \perp \varepsilon$, c) $\eta \perp \nu_0$, d) $\varepsilon \perp \nu_0$, e) $\omega_j \perp \varepsilon$, f) $\omega_j \perp \eta$, g) $\omega_j \perp \nu_0$, h) $\eta \sim$ N(0, σ_η^2), i) $\varepsilon \sim$ N(0, σ_ε^2), j) $\nu_0 \sim$ N(0, $\sigma_{\nu_0}^2$).

In words, the unobservable (η) affecting the agency specific utility is uncorrelated both with the unobservable (ε) affecting the marginal profitability of the applicant's investment and with the unobservable (ν) affecting the application cost. The screening equation unobservables (ω_j) are uncorrelated with all other shocks. As A.7a) shows, there is no restriction on the correlation between ν and ε. A.7h)-j) may be relaxed when we use semi-parametric estimation methods.

The first step is the estimation of the ordered probit the screening equations (4). By using the estimates we can calculate the firms' expected probability that a submitted application gets a particular grade in the two evaluation dimensions. Our assumption that the unobservables are normally distributed allows us to identify the coefficients up to scale.

The second step is to estimate the Tekes decision rule (12). In estimation we use the actual values for the grades from the evaluation of each project. The Tekes decision rule identifies δ, i.e. the effect of observed applicant and project characteristics on the agency specific utility derived from the project. If we impose A.7b) and A.7c), we can estimate (12) using a double-hurdle Tobit model without correcting for selection. To test whether A.7b) and c) hold, we estimate a sample selection double-hurdle Tobit and test for the significance of the Mills ratio term. We also use an alternative, more flexible, approach of nonparametrically estimating (12) by a two-limit version of Powell's (1984) CLAD estimator.

After estimating the agency's screening equation and its decision rule, we calculate the effect of subsidies on the applicant's expected profits, replacing the unobservable parts in the application equation (10) with their estimated counterparts. In step three we then estimate the application and investment equations (10) and (11) by using both ML and a semi-parametric variant of the approach suggested by Das, Newey, and Vella (2003, henceforth DNV).[21]

Our data contains information on the proposed R&D investments, not the realized one. However, we can identify the parameters of the investment equation (11) by estimating a slightly modified version of the equation. The model implies that an applicant strictly prefers proposing a budget based on a maximum subsidy per cent over proposing any smaller amount, and is indifferent between proposing that budget and any

[21] Manski (1989) compares merits of the parametric and non-parametric approaches. Manski argues that, although the nonparametric approach appears to be more flexible, it involves arbitrary exclusion restrictions. Therefore it is not necessarily preferable over the parametric one.

larger amount.[22] Consequently, we will estimate (11) using data on proposed R&D budgets by inserting $\bar{s}$ into (11). As explained in section III.A Tekes sometimes adjusts a proposed budget, e.g. when an applicant applies for subsidies for costs that Tekes cannot cover. To take into account such applicants' mistakes that may inflate the proposed R&D investments, we use the measure 'accepted proposed investment' as our dependent variable in the R&D equation. We test the robustness of our results by using the R&D investment proposed by the applicant as an alternative dependent variable.

The application equation (10) allows us to identify how observed applicant characteristics affect the fixed costs of application without having to resort to an exclusion restriction. Our theoretical model suggests a form for the error term in the application equation and, as a result, we identify the correlation between ν_i and ε_i when using ML. Moreover, we can identify the variance of the error term in the application equation since following theory the coefficient of the summand $\ln \sum_{t=1}^{5} \sum_{k=1}^{5} p_t^c p_k^m \left\{ \int_{\underline{\eta}}^{\overline{\eta}} -\ln\left(1 - s(t,k,\eta)\right)\phi(\eta)d\eta - \left(1 - \Phi(\overline{\eta})\right)\ln(1-\bar{s}) \right\}$ is constrained to unity.[23]

Our model implies that the applicant's best-reply function, $R_i(s_i)$, is increasing in treatment and is heterogenous both with respect to observables and the unobservable profitability shock. Correcting for selection bias by using the application equation (10), we obtain consistent estimates of β that determine the effect of the observable applicant characteristics on the marginal profitability of the R&D-investment. To obtain consistent

[22] Too see this, recall first that the applicant does not know Tekes' type (A.1) and the subsidy share is bounded above at $\bar{s}$. As mentioned in Section III.A, there is also an euro limit to the ex post reimbursements which is based on the proposed budget. Then, since $\partial\Pi/\partial s>0$ by (1), the applicant wants as high a subsidy as possible. Therefore it proposes an optimal project based on the maximum subsidy share, $R^*(\bar{s})$. Proposing anything less risks foregoing profits in case where the actual subsidy turns out to be larger and the applicant subsequently reoptimizes because of the euro limit. On the other hand, the applicant would never want to implement a project larger than $R^*(\bar{s})$, and it is indifferent between announcing $R^*(\bar{s})$ and any larger budget, given the assumption that it cannot misappropriate the funds.

standard errors in the application and investment equations, we bootstrap the whole model (4), (10)-(12) when using both ML and the semi-parametric estimator.

Note also what we cannot identify. In (1) we are unable to identify π_i, the applicant's reservation value, from the constant in X_i. Our cross section estimates are however not affected by unobserved differences in the reservation value. Similarly, in (12) we cannot identify separately *g*, the opportunity cost of government funds, and the constant in δ. Nor can we identify *V*( ), since (12) cannot be integrated to a unique number. Given (5), however, a constant in *V*( ) would imply that a project generates agency specific returns even when the R&D investment is zero. As this is an unappealing scenario, we feel justified in assuming that there is no constant in *V*( ). We are also unable to identify the agency's screening costs (F_i-K_i). This will result in an upward bias in the welfare calculations if these costs are significant. Finally, in the semi-parametric estimation of the application and investment equations, the parameters of the application cost function cannot be identified.

V. Estimation results

We include the following firm characteristics into all estimation equations: age, the log of the number of employees, sales per employee, an SME dummy, a dummy for a parent company, the number of previous applications, a dummy indicating if the CEO acts as the chairman of the board, board size, and a dummy for exporters. We also include industry and region dummies.[24] In the reported specifications, we use a slightly different set of explanatory variables in the screening equations and the Tekes decision rule on the one

[23] This implication of our theoretical model cannot be tested. If we imposed the standard variance normalization, the coefficient of the term would be $1/\sigma_{\varepsilon-\nu}$ instead of unity.

[24] We divide Finland into five regions: Southern, Western, Eastern, Northern and Central Finland. Of these, Eastern and Northern Finland are the least developed. We did try interactions between firm characteristics and industry and region dummies.

hand, and the application and investment equations on the other. For example, we include the squares of the continuous variables only when reporting the estimations of the investment and application equations.[25] The results from the screening equations are reported in the Appendix. We also have estimated the model (by ML) excluding the observations in the 99th size (sales) percentile, with essentially identical results to those reported. Other robustness checks will be taken up in the context of the appropriate estimation.

A. The Tekes decision rule and agency specific returns

In Table 4 we report the estimation results concerning Tekes' decision rule. Recall that the coefficients can be interpreted as the marginal effects of R&D on agency specific benefits. By using ML (column one) we find that the more challenging a project is technically, the higher is its subsidy rate. A one point increase on the 5-point Likert scale leads to a 10 percentage point increase in the subsidy rate. Market risk carries a negative but insignificant (p-value 0.13) coefficient. Firm size obtains a positive and significant (at 10% level) coefficient. A possible interpretation is that in Tekes' view, moving an otherwise identical R&D project into a larger firm creates larger positive externalities, e.g. through higher employee rents. As against Tekes' stated preference that allows a 10 percentage points higher level of maximum subsidy for SMEs, it is unsurprising that SMEs are granted a higher subsidy, everything else equal: The difference is 8.5 percentage points. The corporate governance variables and the number of previous applications have no effect.

We relegate the details of the coefficients of industry dummies to the Appendix. The only industry dummies with significant coefficients are food (p-value .000) and data processing (p-value .081). Using metal manufacturing firms as a reference group, firms in

[25] To speed up the computation of the bootstrap we used LR-tests to narrow the set of explanatory variables in

the food industry received a substantially higher subsidy, of the order of 25 percentage points, whereas data processing firms obtained subsidies that were 6.5 percentage points lower. During our observation period, Tekes was actively seeking applications from the food industry, which at least partially explains the findings concerning the industry.

Another finding left to the Appendix is that regional aspects seem to influence Tekes' decision making: Firms in Eastern and Central Finland obtain subsidies that are 7-10 percentage points higher than they would obtain if they were in Southern Finland. That regional policy matters is, however, debatable, as the city of Oulu, which is located in Central Finland is one of the R&D centers in Finland. Moreover, we find that firms in the depressed and sparsely populated Northern Finland do not get higher subsidies. This finding is perhaps not robust as only 2% of our sample firms come from Northern Finland.

[TABLE 4 HERE]

The above results are obtained under the assumptions A.7b) and A.7c), which maintain that the error in the Tekes decision rule uncorrelated with the errors in the investment and application equations. To test these assumptions, we estimated a two stage selection model. We first estimated a probit application equation[26] and then re-estimated the Tekes decision rule by inserting the Mills ratio into it. The Mills ratio obtained small negative (less than 0.2 in absolute value) and imprecisely estimated coefficients in all of the several specifications that we tried. This suggests that our assumptions A.7b) and A.7c) of no correlation are reasonable. The economic significance of the no-correlation finding is tied to the interpretation of *V*( ). As we will elaborate in sections VI.B and VI.C, if one is willing to assume that *V*( ) captures social surplus, it

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each equation. The second order terms were excluded from the screening equations and the Tekes decision rule based on the LR-tests.

[26] Naturally, the probit was run without the expected subsidy term, but with and without added interactions to improve identification.

will most likely consist of domestic spillovers between firms in Finland. With this interpretation, the finding implies that project specific spillover shocks are unrelated to project specific profitability shocks.

We also tested our assumption that *V*( ), the agency specific utility, is linear in applicant investment as implied by (5). Were *V*( ) non-linear in the applicant's investment, the Tekes decision rule would contain an investment term (*R*) or its interactions with observable applicant characteristics. After incorporating such terms into the Tekes decision rule, we could not reject the Null of (joint) insignificance of the terms. Again, the economic implications are tied to the interpretation of *V*( ). The result suggests that the agency specific benefits from a project are linear in R&D.

We also estimated the Tekes decision rule by a two-limit version of Powell's (1984) CLAD estimator.[27] This allows for nonparametric estimation of (two-limit) censored regressions. As column two of Table 4 shows, the results are relatively close to those obtained using Tobit ML. The only noteworthy differences are that with CLAD, the rubber industry obtains a significant positive coefficient (approximately 0.008 in value, compared with 0.012 for Tobit), and the coefficient of Central Finland is no more significant. There are some relatively large differences between the insignificant coefficients, though.

Finally, to test whether measuring the subsidy per cent by summing subsidies, low-interest loans and capital loans affect the results, we estimated the two-limit Tobit using only subsidies, excluding the loans. Column three reveals that our results are not driven by our definition of the dependent variable.[28]

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[27] The two-limit CLAD was estimated by using the following algorithm: we first estimated a LAD using all 379 observations, then excluded all observations with predicted values less than the minimum or more than the maximum allowed, and re-estimated the LAD. This was repeated until convergence.

[28] We also checked whether the definition of the dependent variable in the Tekes decision rule affects our parameter estimates in the sample selection model (application and R&D investment). The R&D investment

B. Cost of application function

In Table 5 we report the estimates of the application cost function (equation (7)).[29] Age, SME status, CEO being chairman, and parent company status have no statistically significant effect, but firm size has a non-linear decreasing effect on application costs. Sales per employee increase application costs. One interpretation is that firms producing high value added products have complicated R&D projects based on soft information that are laborious to write down. Another is that because the opportunity costs of the effort of making and promoting an application are probably far greater than the direct monetary costs of filling in and filing it, firms with high value current production have higher opportunity costs of applying. The size of the board has a decreasing effect on application costs. This may reflect the role of external knowledge in lowering application costs. Exporters have lower costs, maybe because they are relatively more experienced in dealing with government bureaucracy than non-exporting firms.

[TABLE 5 HERE]

The number of past applications has a nonlinear effect, first decreasing and then, after 141 applications, increasing application costs. Increasing the number of past applications from non-applicants' median of zero to applicants' median of two decreases application costs by 35%. One prior application decreases costs by 20% and four by 58%. It seems that learning by doing is going on. Given that our data is cross sectional, however, it is possible that instead of being attributed to path-dependence, the results are generated by unobserved heterogeneity.

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equations' parameters are virtually identical, as are most of the parameters of the application equation. All parameters in the application equation are within one standard deviation of each other.

[29] We only present results from the model where the log of accepted proposed investment was the dependent variable in the 2nd stage investment equation as results using the log of proposed investment yielded essentially identical results.

C. Investment equation

Recall that our investment equation (10) identifies the effects of exogenous variables on marginal profitability of R&D investment. In view of the received R&D literature, it is likely that unobserved heterogeneity accounts for a substantial part of the marginal profitability of R&D. This is also what we find, as Table 6 shows. Firms with higher value-added current production have higher marginal profitability of R&D whereas it appears to be lower in firms with CEOs as chairmen. Other findings are not robust over specifications. In column one where we report the results from the specification with the quadratic terms the number of previous applications and being an exporter also carry significant coefficients.[30] In the specification without the quadratic terms, we find that larger firms, measured by the log of the number of employees, have higher marginal profitability of R&D. Henderson and Cockburn (1996), the only other study known to us that employs project level data, report a similar result.

To test the robustness of our results, we estimated the model using DNV's semi-parametric sample selection estimator. We imposed otherwise the structure of the ML specification, but allowed the additively separable error terms to have an unknown distributions. The results, presented in column three of Table 6, are in line with the ML estimates: Most coefficients are within the ML 95% confidence intervals. This suggests that our ML distributional assumptions are not biasing the parameter estimates. The propensity score carries a negative coefficient as expected (significant at 12.5% level). Following DNV we interpret that there is evidence in favor of normal disturbances, because cross-validation (CV) suggests that no higher order terms of the propensity score are needed. [31]

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[30] Several industry and region dummies carried significant coefficients, too.

[31] We used the same trimming and transformation DNV. The transformation gives exact sample selection correction for Gaussian disturbances. The trimming explains the difference in the sample size compared to ML estimations. We tried up to the 4th order terms for the variable capturing the effect of subsidies on

[TABLES 6 AND 7 HERE]

Finally, we estimated the investment equation using the R&D investment proposed by the applicant as an alternative dependent variable. The results, presented in column four, are close to those in column one.[32] The one notable difference is that the coefficient of the CEO as chairman variable, although close in value, is no longer statistically significant. It thus seems that the definition of the dependent variable is not driving the results.

D. Covariance structure

As Table 7 shows, we are able to identify the variances of all error terms, and the covariance between the unobservables in the application and investment equations. The coefficient determining the variance share of the unobservable of the investment equation in the unobservable of the application cost function (equation (7)) obtains a value of 1.5. Ceteris paribus, the higher the unobserved marginal profitability of the R&D project of a firm, the less likely it is that the firm will submit an application. Similar to the finding that sales per employee increase application costs, it could be that projects with higher marginal profitability of R&D are more complicated involving tacit knowledge and are therefore more difficult to describe in an application. Moreover, the application costs are essentially opportunity costs, which should be higher for projects with higher marginal profitability of R&D.

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expected discounted profits in the 1st stage, and started from the ML specification. CV indicated that we should include the subsidy-terms up to the 3rd order, but should not include interactions of the other explanatory variables. In the 2nd stage, we kept the same specification as in ML, and experimented with including up to the 4th order transformation of the propensity score (without interactions with explanatory variables). Only the 1st order propensity score variable obtained a significant coefficient, and CV confirmed that we only should use the 1st order propensity score. CV-values are reported in the Appendix. We used a Gram-Schmidt ortho-normalization for the 3rd and 4th order terms in both stages.

[32] The results using the restricted specification are close to those reported in column two.

VI. Implications of the results

The structure of our model can be utilized to back out a number of figures that provide insights into the efficiency of R&D investment and subsidies. In addition the estimated model can be used to analyze the effects of application costs. We first report implications about expected benefits and rates of return to R&D, then discuss our findings on treatment effects and finally present implications about the application costs. We conclude by characterizing the distribution of R&D benefits.

In calculating the figures, a key idea is to exploit the information on unobservables that the covariance structure and the application equation yield. Since the indicator function in (10) takes value one for applicants and zero for non-applicants, we can condition the expected values of the unobservables on the value of the indicator function. We base the calculations on results derived using the accepted proposed investment as the dependent variables and report medians. All our figures refer to expectations formed prior to the launch of a project. Consequently, when we talk about profits, utility, welfare or rate of return, we always mean expected discounted ones. For brevity, we drop the 'expected discounted' from the text. In order to analyze the differences between the group of non-applicants and the group of applicants, we report all the figures for both groups.

A. Profitability and the rate of return to R&D

Profitability of R&D and the rate of return to R&D indicate the efficiency or productivity of R&D investments. According to our model, profits on the non-applicants' projects are 13 million euros whereas they are only 2.7 million euros on the applicants' projects. In addition we find that in the absence of subsidies, the applicants' projects generate an agency specific median utility of 68 000 euros, the corresponding utility from non-applicants' projects being 319 000 euros. Applicants' projects are thus privately and socially less valuable than those of non-applicants. However, the ratio of agency specific to private median benefits is somewhat higher for applicants than non-applicants.

The estimated private returns to R&D investment are very high for applicants (median close to 1000%), and even higher for non-applicants. Joint returns to R&D investment are appreciably higher, but the differences are dominated by the very high private returns. The private returns may seem too high for comfort even keeping in mind that these figures are based on firms' plans rather than on realizations, but most of the prior literature's results also indicate very high returns. For example, Griliches (1964) estimates a social return of 13$ on a dollar of R&D in agriculture, Mansfield et al. (1977) report an average social rate of return of over 80% and Griliches (1998, pp. 67) reports private rates of return in the interval [.03, 1.03]. More recently, Udry and Anagol (2006) report returns of 300% for pineapple cultivation in Ghana and explain it by appealing to unobserved returns to innovation and experimentation related to this relatively new (in Ghana) crop.

The relative dominance of private returns is understandable, because Tekes and the firms operate in a small open economy from which most of the consumer surplus and spillovers flow abroad.[33] If Tekes is maximizing domestic welfare, it should ignore those effects, implying that private returns constitute a large part of joint returns. The distribution of private and, hence, joint returns to R&D, is skewed (see Figure 1 for non-applicants' private returns w/o subsidies), confirming earlier results (Pakes 1986, Scherer and Harhoff 2000).

[FIGURE 1, TABLE 8 HERE]

[33] The literature on R&D, geography and trade (see e.g. Eaton and Kortum 2002) finds that much of the spillovers are international.

B. Treatment effects

The literature on treatment effects emphasizes the effects of the treatment on the treated. In our case this treatment effect is the effect of the subsidy on the profits of subsidized applicants, i.e the change in profits due to subsidy. We call this the private treatment effect. It is heterogenous across firms as it depends on both observable and unobservable applicant characteristics. In addition to this standard treatment effect, our approach allows the identification of several other relevant treatment effects.

First, our model suggests that a subsidy has an effect on the agency beyond that on the applicant. We name the subsidy-induced change in the agency specific utility the subsidy the agency treatment effect.[34] If one assumes that the agency is a benevolent social planner, *V*( ) will capture all general equilibrium effects of a treatment outside those appropriated by the applicant. Consequently the joint effect of the treatment on the agency and the subsidized applicant will constitute the social treatment effect, i.e., increase in joint welfare due to the subsidy.

Second, the inclusion of application costs in the analysis makes it possible to differentiate between gross and net effects of the treatment. Usually only gross treatment effects, i.e. those that do not take into account application costs, are analyzed. Third, in addition to the actual treatment effect[35] (treatment on the treated), we can calculate the expected treatment effect on the applicants and the non-applicants. In other words, our model makes it possible to touch upon the issue of what would have been the effect of the treatment on the non-applicants.

[34] The calculations are based on the assumption that the shadow cost of taxes, *g*, is 1.2. Kuismanen (2000) estimates the dead-weight loss of existing Finnish taxation to be 15% using labor supply models. Both the constant of integration and the fixed costs of screening applications (i.e. F_i=K_i) are ignored.

[35] In other words, actual means that the treatment is realized. Naturally, these are still expected discounted effects.

In reporting the figures, we thus divide the treatment effects into private (firm), agency, and joint treatment effects. Joint refers to the sum of private and agency treatment effects. Note that all these treatment effects are expected, not realized, ones as our calculations reflect the expected effect of the treatment prior the launch of the project. The difference between treatment effect and expected treatment effect in the text is that the former is calculated based on the actual, the latter using the anticipated, subsidy.

We first report the net treatment effects based on actual treatments on the subsidized applicants. In the text below, we always refer to net figures unless otherwise stated. The median increase in the subsidized applicants' profits due to subsidies is 30 000 euros whereas the median agency treatment effect is 44 000 euros. Together these generate the median joint treatment effect (welfare increase) of 74 000 euros. The median increase in the subsidized applicants' profits ignoring the application costs is 65 000 euros. Thus, ignoring application costs severely biases the estimated effects upwards.

The median joint rate of return on the subsidy is 0.80; ignoring application costs the corresponding figure is 1.22.[36] The joint rate of return on the subsidy program is 0.74, taking into account also the application costs of the applicants that did not receive a subsidy.[37] Ignoring application costs yields a joint rate of return on the subsidy program of 1.22. Note that the rates of return taking into account application costs are smaller than the estimate we use for the shadow cost of public funds (g=1.2), meaning that costs overweigh the benefits. We next compare the expected treatment effects for the non-applicants and the applicants using expected subsidies.

The median increase in the applicants' and non-applicants' profits due to expected subsidies are 11 000 euros and -1.9 million euros respectively. The corresponding figures

[36] The joint rate of return is defined as the sum of agency specific utility and firm profits net of application cost divided by subsidy amount in euros, where the subsidy amount in euros equals subsidy times the expected R&D investment, conditional on the subsidy.

for gross profits are 46 000 euros vs. 206 000 euros. This highlights how the high application costs make it unprofitable for the non-applicants to apply. To make the comparisons between non-applicants and applicants more meaningful, we ignore the applications costs below. As indicated above, the median increase in the applicants' gross profits due to expected subsidies is substantially less than the median increase in the non-applicants' profits (46 000 euros vs. 206 000 euros). A comparison of the figures with the private returns without subsidies, however, shows that the relative increase is higher for applicants than non-applicants. The non-applicants' projects also generate higher median increase in the agency specific utility than the applicants' projects (77 000 euros and 19 000 euros respectively). Figure 2 displays the distribution of the gross treatment effect for both applicants (left graph) and non-applicants (right graph) using expected subsidies as the treatment. It is evident that non-applicants' treatment effects are larger on average and that there is substantial heterogeneity.

[FIGURE 2 HERE]

We have also calculated rates of return on expected subsidies, again ignoring application costs. The rates of return in case of subsidized applicants are higher with expected subsidies than with actual ones, because some applicants who would have generated very high returns if they had received expected subsidies, received lower subsidies and therefore generate lower returns. The rate of return on the subsidy program using the expected subsidy is 1.39 for applicants and the same for non-applicants. The median joint rate of return on expected subsidy is 1.38 for applicants and 1.37 for non-applicants.

The private and agency, and therefore, joint expected treatment effects are substantially lower for applicants, while the joint rates of return are similar for applicants

[37] The joint rate of return on the subsidy program is the overall benefits due to subsidies divided by the

and non-applicants. The reason why applicants' projects are submitted to Tekes is that they involve much lower application costs than the projects that are not submitted. The median costs of application is 34 000 euros for applicants compared to 2 million euros for non-applicants. This is generated by the positive correlation between the shock to the marginal profitability of R&D and the application cost shock. Some privately and jointly profitable projects thus have very high private opportunity costs of applying.

C. Distribution of returns

In the following we assume that *V*( ) reflects returns to the Finnish society that are not appropriated by the firm. It is of course questionable whether Tekes' decisions reflect social returns or not. However, for the sake of the argument, let us proceed under that assumption. As mentioned, even if this is the case, *V*( ) does not measure the global social surplus: it is very likely that most of the consumer surplus and at least some of the spillovers stemming from Finnish innovations will diffuse outside Finland. Therefore, one can think that *V*( ) mainly consists of domestic technological spillovers. This interpretation is supported by our observation that technical challenge ratings gain a significant role in the Tekes decision rule.

We first discuss how agency specific returns vary with R&D investments. This immediately yields the variation of the agency specific returns with subsidies, given the complementarity of the investment and subsidy levels in our model. We then describe and characterize the joint distribution of private and agency specific benefits from R&D. Much of the growth and R&D spillover literatures assume that spillovers are increasing in R&D: Studying the distribution of agency specific returns allows us to test this assumption in our data. The joint distribution in turn is central in uncovering whether the social returns of R&D grow in proportion to private returns or not.

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overall costs of subsidies, ignoring the shadow cost of taxes.

Recall that we can estimate the profits from a firm's R&D project conditional on its decision to apply for a subsidy (E[Π( )|*X*, *d*]), and the agency specific utility from the project (E[*V*]=E[$Z\hat{\delta}$]E[*R*]). As before, in calculating E[$Z\hat{\delta}$], we set $\underline{g}$=1.2 and F_i=K_i, yielding -0.14 as our estimate of the constant. Using this value, E[$Z\hat{\delta}$] is nonnegative for 97% of our observations: Figure 3 depicts the distribution of E[$Z\hat{\delta}$]. This implies that E[*V*( )] is increasing in R&D investments and, hence, in the subsidy rate, for almost all projects in our data. The figure also reveals that for most projects, the expected increase in spillovers is between 0.25 and 0.5 per one euro of R&D. For 99% of firms, a one euro increase in R&D leads to a less than 0.7 euro increase in spillovers.[38]

[FIGURES 3 AND 4 HERE]

Figure 4 presents the joint distribution of private and agency specific returns, and a non-parametric estimate of E[*V*( )] as a function of E[Π( )|X, *d*].[39] Regressing E[*V*( )] on E[Π( )|X, *d*] and a constant yields a highly significant coefficient of 0.022, while the raw correlation is 0.875 and significant at the 1% level. The estimated nonparametric relationship between the agency specific and private returns seems to be almost linear for most of the interval.

VII. Conclusions

We develop a new approach to characterize the determinants and the distribution of R&D returns, to measure treatment effects and to improve our understanding of how an R&D subsidy program works. The method exploits a structural treatment program model and firm and R&D project level data. We find that spillover and profitability shocks are unrelated and spillovers are linear in R&D investments. The returns appropriated by the

[38] We trimmed the sample used in Figure 3 at the 99th percentile.

[39] We have trimmed the sample at the 95th percentile to aid the visualization of the distribution. The estimate is a *k*-nearest neighbor estimate.

agency but not by the firm are dominated by private returns. Both private and social rates of return to R&D investment are large and their distribution skew. Large firms' projects yield higher agency specific returns. Profitability and application cost shocks are positively related, implying that firms do not apply for subsidies for the privately most profitable projects.

On the treatment effect side we are able to extend the number of identified treatment effects. We find considerable heterogeneity in all of them, generated both through observables and unobservables. We also compare the expected effects of subsidies between non-applicants and applicants had the non-applicants and the applicants been granted the anticipated subsidy. The findings indicate that both the private and the agency treatment effects are substantially lower for applicants, while the expected joint rates of return are similar for applicants and non-applicants. In general, our results suggest that ignoring application costs is recommendable neither in the research of R&D subsidy treatment effects nor in practical policy making, as it leads to a significant upward bias. For example, the median increase in the subsidized applicants' profits due to subsidies is 30 000€, while the corresponding figure ignoring application costs is 65 000€.

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Table 1
Descriptive Statistics

	Mean	S.d.	Min.	Max.
Age, years	12.320	9.3453	1	97
# Employees	35.229	257.174	1	13451
Sales/employee, 1000 euros	164.920	2156.961	0	206875.5
Exporter	0.063	0.244	0	1
SME	0.975	0.157	0	1
CEO is chairman of board	0.141	0.348	0	1
Board size	4.350	2.003	1	10
# past Tekes applications	0.575	3.488	0	146
Applicant	0.084	0.277	0	1

NOTES: There are 10944 observations. Data sources: Asiakastieto Ltd. otherwise; for data on applications, Tekes.

Table 2
Conditional Descriptive Statistics

	Non-Applicants	Applicants	Rejected Applicants	Successful Applicants
Age	12.355 (9.326) [10]	11.940 (9.557) [10]	11.777 (9.964) [9]	11.983 (9.452) [10]
# Employees	21.200 (122.282) [5]	189.001 (775.862) [26]	101.269 (187.503) [21]	212.453 (866.674) [27]
Sales/employee	168.852 (2252.692) [77.55]	121.826 (54.996) [89.72]	104.831 (94.238) [82.95]	126.369 (167.307) [91.58]
Exporter	0.059 (0.236)	0.109 (0.312)	0.119 (0.325)	0.107 (0.309)
SME	0.9860 (0.1173)	0.850 (0.357)	0.855 (0.352)	0.849 (0.358)
CEO is chairman of board	0.141 (0.348)	0.149 (0.356)	0.176 (0.382)	0.141 (0.349)
Board size	4.183 (1.873) [4]	6.177 (2.431) [6]	5.850 (2.285) [5]	6.265 (2.462) [6]
# past Tekes applications	0.247 (1.283) [0]	4.163 (10.657) [2]	3.228 (10.933) [1]	4.413 (10.576) [2]
Nobs.	10029	915	193	722

NOTES: Number reported are mean, (standard deviation), and for other than [0,1] variables, [median]. Data sources: Asiakastieto Ltd. otherwise; for data on applications, Tekes.

Table 3
Descriptive Statistics of Tekes and Application Variables

	All Applicants	Successful Applicants	Rejected Applicants
Applied amount, euros	634294 (1254977)	700378.2 (1363460)	385790 (657539.8)
Applied for subsidy only	0.591 (0.492)	0.482 (0.500)	1.000 (0.000)
Technical challenge	2.088 (0.982) {582}	2.312 (0.872) {426}	1.474 (1.006) {156}
Risk	2.189 (0.937) {422}	2.150 (0.925) {326}	2.302 (0.937) {96}
Granted subsidy rate	-	0.316 (0.126)	-
Granted subsidy only	-	0.839 (0.600)	-
Nobs.	915	722	193

NOTES: Datasource: Tekes. Reported numbers are mean, standard deviation, and {nobs}, the last in case it deviates from that reported on the last row.

Table 4
Tekes Decision Rule Results

Variable	(1) ML Dep. var. subsidy-intensity (all finance)	(2) CLAD Dep. var. subsidy-intensity. (all finance)	(3) ML Dep. var. subsidy-intensity (subsidies only)
Risk	-.018	-.020**	-.019
	[-.041 .005]	[-.039 -.001]	[-.048 .009]
Technical	.100***	.094***	.120**
challenge	[.076 .124]	[.074 .113]	[.090 .150]
Age	-.001	.0003	-.001
	[-.003 .001]	[-.0017 .0023]	[-.004 .002]
Log	.0164*	.024***	.031***
employment	[-.003 .036]	[.008 .040]	[.007 .055]
Sales /	.000036	.000034	.000036
employment	[-.000136 .000276]	[-.000083 .000151]	[-.00017 .000243]
SME	.085*	.068*	.093*
	[-.001 .170]	[-.003 .138]	[-.011 .197]
Parent company	.006	.016	.014
	[-.040 .053]	[-.023 .055]	[-.043 .070]
# previous	-.001	-.002	-.003
applications	[-.006 .004]	[-.006 .002]	[-.009 .003]
CEO also	.001	-.018	-.013
chairman	[-.053 .055]	[-.064 .028]	[-.080 .055]
Board size	-.007	-.0001	-.009
	[-.017 .003]	[-.0084 .0082]	[-.021 .003]
Exporter	-.042	-.016	-.079*
	[-.107 .023]	[-.069 .038]	[-.161 .002]
Constant	-.060	-.103	-.197**
	[-.217 .098]	[-.233 .028]	[-.393 -.001]
σ_η	.189***	-	.225***
	[.173 .206]		[.203 .247]
Nobs.	379	379	379
LogL.	-18.636	-	-91.763
Wald	0.000	-	0.000
Linearity 1	0.690	-	-
Linearity 2	0.313	-	-
Sample sel.	.068	-	-
	(.051)		

NOTES: Reported numbers are coefficient and [95% confidence interval]. Wald is the p-value of a Wald test of joint significance of all RHS variables. All specifications include industry and region dummies.

Linearity 1 = the p-value of a LR-test of including the proposed R&D investment into the equation.

Linearity 2 = the p-value of a LR-test of including the proposed R&D investment into the equation, plus interactions between it and age, log employment, and sales/employee.

Sample sel. = coeff. and (s.e.) of the Mills ratio term when the 1(apply) specification same as in Table 5.

***, **, and * denote significance at 1, 5, and 10% level.

In columns (1) and (2), the dependent variable is the proportion of expenses that the Agency covers, defined as the sum of all three types of financing the Agency grants (in euros, see main text) divided by accepted proposed investment. In column (3), the dependent variable is the subsidy (in euros) divided by the accepted proposed investment.

Table 5
Application Cost Function Results

Variable	Value
Age	.008
	[-.015 .630]
Age sq.	4.413e-05
	[-.006 .0004]
Log of employment	-.293**
	[-15.151 -.014]
Ln(emp) sq.	.040**
	[.008 1.497]
Sales/employee	.002*
	[-.0003 .014]
Sales/emp. Sq.	-1.974e-0.7
	[-8.11e-07 3.69e-06]
SME	.093
	[-2.334 3.488]
Parent company	-.085
	[-6.661 .128]
# Previous applications	-.171***
	[-6.606 -.078]
# Prev appl. sq.	.001***
	[.0006 .051]
CEO is chairman	-.285
	[-1.550 .409]
Board size	-.075**
	[-3.032 -.008]
Exporter	-.598**
	[-10.405 -.090]
Constant	13.110***
	[11.156 100.589]
Nobs	10751
LogL.	-18.636
Wald (d.f. 29)	0.000

NOTES: Reported numbers are coefficient and [95% confidence interval]. Statistics refer to the probit 1st stage regression from the results of which the cost function coefficients have been backed out. Confidence intervals are estimated using a bootstrap with 400 repetitions. The specification includes industry and regional dummies.
Wald is the p-value of the joint significance of all explanatory variables in the probit 1st stage regression.
***, **, *, and [a] denote that the whole 99%, 95%, 90% and 85% confidence interval has the same sign as the coefficient estimate.

Table 6

R&D Investment Function Results

Variable	(1) ML Dep. var. accepted proposed investment	(2) ML Dep. var. accepted proposed investment	(3) DNV Dep. var. accepted proposed investment	(4) ML Dep. var. proposed investment
Age	-.005	.002	.0001	-.005
	[-.025 .012]	[-.007 .007]	[-.030 .025]	[-.027 .006]
Age sq.	.0002	-	.0002	.0001
	[-.00008 .0005]		[-.0002 .0005]	[-.00008 .0004]
Log of employment	-.077	.041**	-.024	-.130
	[-.226 .132]	[.014 .159]	[-.362 .327]	[-.268 .206]
Ln(emp) sq.	.015	-	-.001	.022
	[-.021 .038]		[-.039 .036]	[-.017 .040]
Sales/empl.	.001**	0.0009***	.001**	.001*
	[.00002 .002]	[.0005 .002]	[.0003 .003]	[-.00003 .002]
Sales/emp. sq.	-1.95e-07	-	-2.9e-07	-1.53e-07
	[-7.74e-07 1.28e-06]		[-1.01e-06 1.33e-06]	[-6.27e-07 1.66e-06]
SME	-.258	-.280	-.011	-.063
	[-.726 .166]	[-.523 .096]	[-.766 .815]	[-.511 .349]
Parent company	.020	.064	-.091	-.035
	[-.166 .208]	[-.072 .271]	[-.438 .236]	[-.183 .182]
# Previous applications	-.047**	-.007	-.295	-.047[a]
	[-.082 -.013]	[-.018 .004]	[-.748 .174]	[-.070 .006]
# Prev appl. sq.	.0003**	-	.002	.0003
	[.0001 .0013]		[-.005 .011]	[-.0001 .0007]
CEO is chairman	-.182*	-.194**	-.158	-.107
	[-.354 .022]	[-.366 -.011]	[-.368 .066]	[-.290 .100]
Board size	-.008	.008	-.065	.007
	[-.038 .036]	[-.015 .056]	[-.207 .086]	[-.020 .063]
Exporter	-.255*	-.199	-.398	-.118
	[-.455 .0029]	[-.355 .047]	[-.849 .162]	[-.258 .173]
Propensity score	-	-	-13.363[a]	-
			[-28.604 3.440]	
Constant	13.234***	12.416***	-	13.002***
	[11.909 14.123]	[10.950 12.734]		[10.923 13.536]
Nobs.	722	722	688	914
Wald (d.f. X)	0.000	0.000	0.000	0.000
$\ln(1-\bar{s})$	0.158			-0.718
	(0.181)			(0.740)

NOTES: Reported numbers are coefficient and [95% confidence interval]. Confidence intervals are based on a bootstrap with 400 repetitions. In columns (1)-(3) the dependent variable is the log of accepted proposed investment: in column (4) it is the log of proposed investment.

Wald is the p-value of joint significance of RHS variables. The constant is not identified when using DNV.

$\ln(1-\bar{s})$ coefficient reports the coefficient and the (p-value) of a χ^2-test of difference from unity. The SME dummy was excluded from the test regressions due to collinearity with $\ln(1-\bar{s})$.

***, **, *, and [a] denote that the whole 99%, 95%, 90% and 85% confidence interval has the same sign as the coefficient estimate.

Table 7
Covariance Structure Results

Variable	Value
σ_{ε} Standard deviation of the investment equation shock	1.120*** [.834 1.256]
σ_{η} Standard deviation of the Tekes specific utility (=V( )) shock	.189*** [.173 .206]
$\sigma_{\upsilon 0}$ Standard deviation of the uncorrelated part of the application cost function shock	.456*** [.111 12.552]
$1+\rho$ Measure of the variance share of ε in υ	1.485*** [1.052 11.010]
$\rho_{\varepsilon\upsilon}$ Correlation between ε and the application equation error term	-.766*** [-.879 -.153]

NOTES: Reported numbers are coefficient and [95% confidence interval]. For all but σ_{η}, these are based on a bootstrap with 400 repetitions. For σ_{η}, it is based on the estimated covariance matrix.
***, **, and * denote significance at 1, 5, and 10% level.

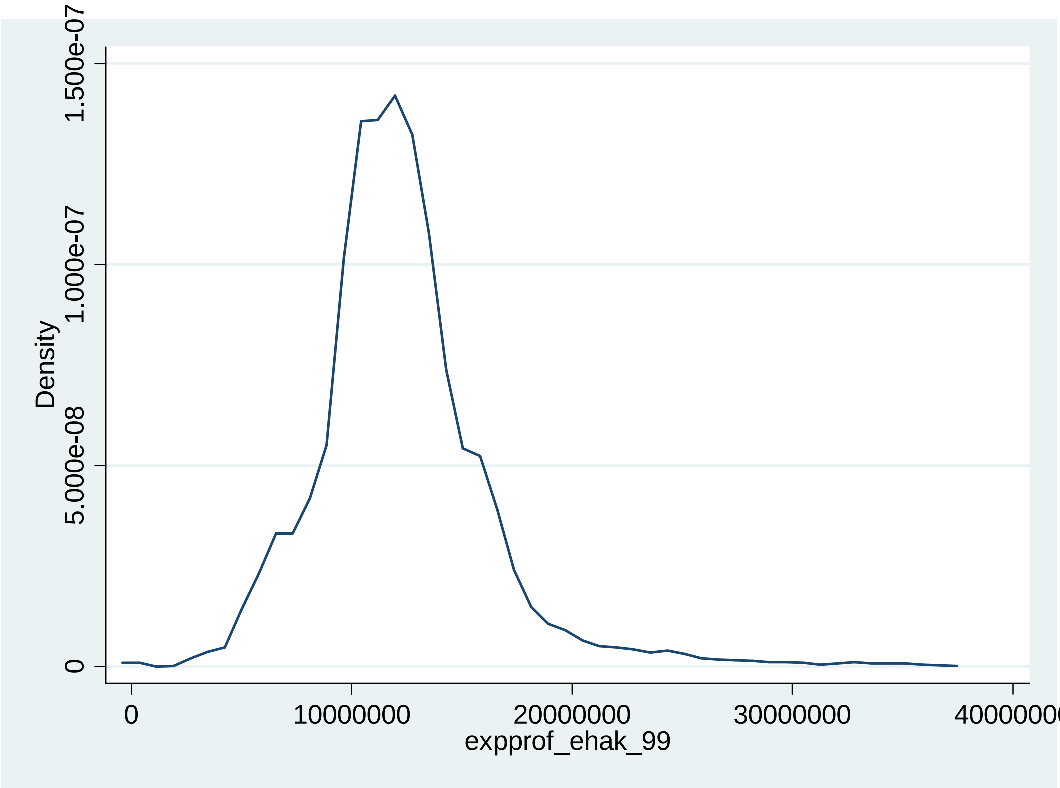

Figure 1: Distribution of expected discounted profits of non-applicants (with no subsidies).

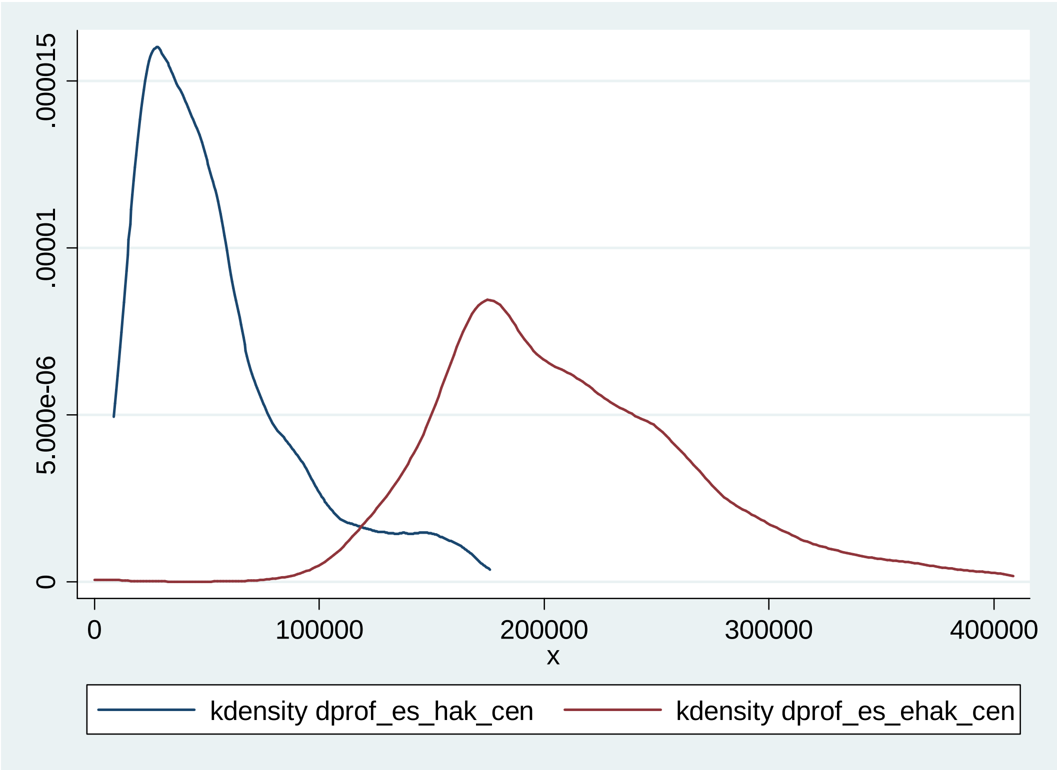

Figure 2: Distribution of the treatment effect for applicants (left graph) and non-applicants using expected subsidies as the treatment.

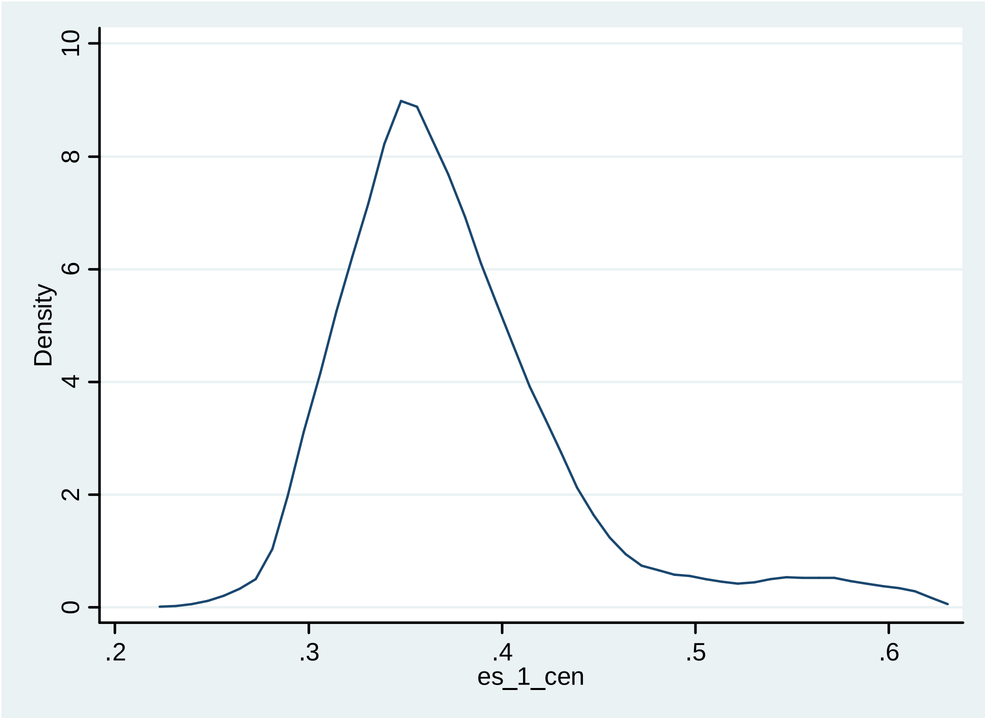

Figure 3: Distribution of $\mathrm{E}[Z\hat{\delta}]$.

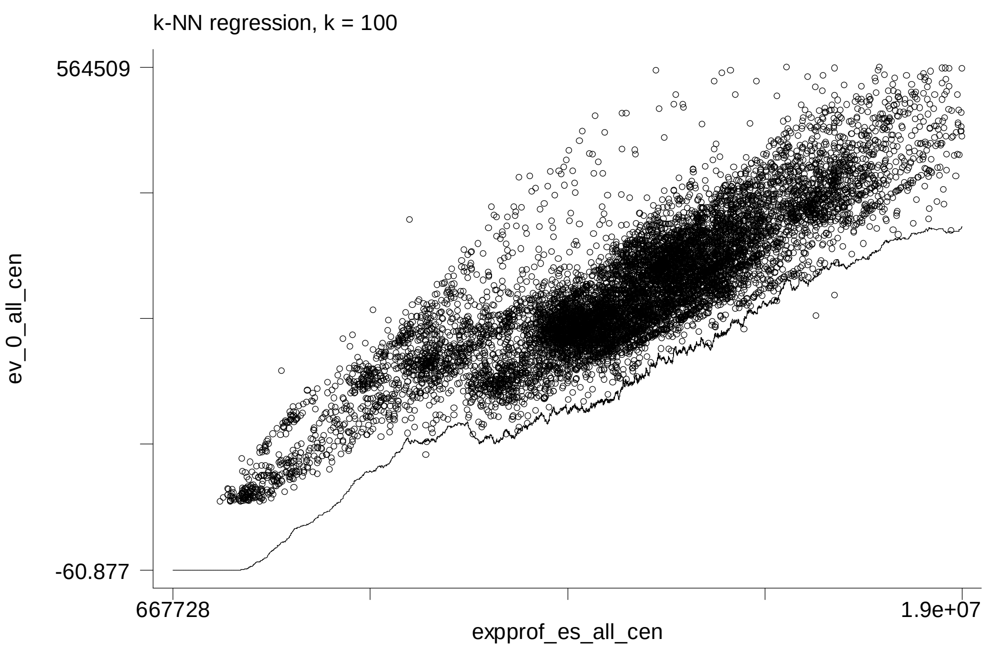

Figure 4: Joint distribution of expected discounted private and joint benefits from R&D w/o subsidies, all firms.

APPENDIX A

In this Appendix, we report the ordered probit estimation of the Tekes grading process; descriptive statistics of a) the whole application sample b) the application sample who have strictly positive accepted proposed investments, and c) the application sample for which we observe grades in both evaluation dimensions; industry and region dummy descriptive statistics and their coefficients for the estimated equations; and the cross-validation figures for the 1st and 2nd stage DNV estimations.

We have different applicant samples in the estimations of the two grading dimensions, because sometimes we only observe one or the other grade for an application. During our observation period, Tekes did not uniformly store grading data in their central database, from which our data has been collected. We use the estimation results to create the probabilities of getting a particular grade for all the 10751 (10944) observations in the estimation sample.

A.1. The evaluation equations

In the technical challenge estimation, sales per employee, number of previous applications, board size, and industry dummies (chemical, industry, electric engineering, data processing, and R&D services) increase the probability of getting a high grade in evaluation of technical challenge. Having a CEO as chairman and being in the food or paper industry decreases the probability of getting a high grade.

In the market risk estimation, sales per employee and a number of industry dummies have a negative effect on the probability of obtaining a high risk rating (high meaning higher risk). The industry dummies that carry significant negative coefficients are paper, other manufacturing, and telecoms. Being located in Western Finland also decreases the probability of being classified as high risk.

Table A.1
Estimation of the Evaluation Equations

Variable	Technical Challenge	Risk
Age	| .003	| -.0042379
	[-.007 .013]	[-.0164625 .0079868]
Log Employees	.008	-.0536393
	[-.076 .092]	[-.1538962 .0466177]
Sales/employee	.001***	-.0008665*
	[.0002 .002]	[-.0017846 .0000516]
SME	-.101	| .0600485
	[-.476 .274]	[-.3851782 .5052751]
Parent Company	-.002	| -.1378355
	[-.206 .202]	[-.3769572 .1012863]
# Previous Applications	.021*	-.0189169
	[-.003 .044]	[-.045992 .0081582]
CEO is chairman	| -.247**	-.0118448
	[-.487 -.006]	[-.2940517 .270362]
Board size	.078	.0331881
	[.034 .121]	[-.0160126 .0823889]
Exporter	| .170	.2292716
	[-.114 .454]	[-.1084814 .5670247]
Nobs.	582	422
LogL.	-753.92882	-528.7958
Joint Significance	0.000	0.0000

NOTES: reported numbers are coefficient and [95% confidence interval]. Joint Significance is the p-value of a LR test of joint significance of all explanatory variables. Both specifications include industry and region dummies.

***, **, and * denote significance at 1, 5, and 10% level.

A.2. Descriptive statistics of the applicant samples

Table A.2 presents the descriptive statistics for the three samples of applicants mentioned above. As can be seen, the differences are minor; judging on observables, we are unlikely to have a selection problem among applicants in the subsidy equation. The only potentially worrisome difference is that in the smallest sample, the mean number of previous application is lower (2.8) than in the other two (4.2 and 4.4). The standard error also declines. Also, the proportion of telecom firms and firms in Eastern Finland are somewhat lower. As we report in the main text, we found no evidence for sample selection after testing it against the whole sample.

Table A.2
Descriptive Statistics of Different Applicant Samples

Variable	All Applicants	Applicants with strictly positive proposed accepted investment	Applicants for whom grades in both evaluation dimensions are observed
Age	11.940	11.983	11.425
	(9.557)	(9.452)	(8.961)
Log Employees	3.416	3.469	3.213
	(1.787)	(1.786)	(1.684)
Sales/employee	121.826	126.369	120.252
	(154.996)	(167.307)	(128.096)
SME	.850	.849	.879
	(.357)	(.358)	(.327)
Parent company	.510	.525	.478
	(.500)	(.500)	(.500)
# Previous applications	4.163	4.413	2.765
	(10.657)	(10.576)	(4.545)
CEO is chairman	.149	.141	.174
	(.356)	(.349)	(.380)
Board size	6.177	6.265	6.090
	(2.431)	(2.462)	(2.367)
Exporter	.109	.107	.116
	(.312)	(.309)	(.321)
Food	.035	.037	.032
	(.184)	(190)	(.175)
Paper	.051	.051	.037
	(.221)	(.221)	(.189)
Chemicals	.032	.035	.026
	(.175)	(.183)	(.160)
Rubber	.062	.061	.061
	(.242)	(.239)	(.239)
Metals	.079	.080	.069
	(.269)	(.272)	(.253)
Electric	.101	.108	.106
	(.301)	(.311)	(.308)
Radio and TV	.040	.039	.047
	(.197)	(.193)	(.213)
Other manufacturing	.093	.091	.087
	(.290)	(.288)	(.282)
Telecoms	.009	.010	.003
	(.093)	(.098)	(.051)
Data processing	.207	.197	.259
	(.405)	(.398)	(.438)
R&D	.148	.147	.129
	(.355)	(.354)	(.336)
Western Finland	.321	.321	.351
	(.467)	(.467)	(.478)
Eastern Finland	.115	.125	.058
	(.319)	(.331)	(.234)
Central Finland/ Oulu	.085	.079	.087
region	(.279)	(.270)	(.282)
Northern Finland /	.022	.019	.029
Lapland region	(.146)	(.138)	(.168)
Nobs.	915	722	379

A.3. Descriptive statistics of the industry and region dummies for the whole sample

Table A.3
Descriptive Statistics of the Industry and Region Dummies for the Whole Sample

Indicator	Mean (s.d.)
Agriculture	.0001
	(.010)
Food	.045
	(.207)
Paper	.061
	(.239)
Chemicals	.015
	(.120)
Rubber	.056
	(.229)
Metals	.139
	(.346)
Electric	.046
	(.209)
Radio and TV	.015
	(.120)
Other manufacturing	.188
	(.391)
Telecoms	.009
	(.095)
Data processing	.105
	(.307)
R&D	.196
	(.397)
Southern Finland	.453
	(.498)
Western Finland	.386
	(.487)
Eastern Finland	.078
	(.268)
Central Finland/Oulu region	.061
	(.240)
Northern Finland/Lapland	.023
	(.149)

NOTES: there are 10944 observations.

A.4. Coefficients of industry and region dummies

Table A.4
Estimated Industry and Region Dummy Parameters

Variable	Tekes Decision Rule Table 4			Application Cost Function Table 5	R&D Investment Function Table 6			
Column	(1)	(2)	(3)		(1)	(2)	(3)	(4)
Food	.246***	.241***	.312***	.045	-.649***	-.612***	-.518*	-.522***
	[.122 .370]	[.137 .345]	[.163 .461]	[-1.593 3.204]	[-1.012 -.265]	[-1.00 -.269]	[-.968 .025]	[-.884 -.155]
Paper	-.017	.018	.0003	.070	.034	.017	.144	.183
	[-.140 .106]	[-.080 .116]	[-.1488 .1494]	[-0.632 10.919]	[-.354 .364]	[-.350 .343]	[-.395 .808]	[-.203 .482]
Chemicals	.094	.052	.132	.759	.213	.264	.232	.163
	[-.039 .228]	[-.060 .164]	[.029 .292]	[-10.372 1.601]	[-.253 .744]	[-.162 .752]	[-.573 .889]	[-.320 .723]
Rubber	.012	.080	.008*	.191	.099	.103	.109	.080
	[-.084 .108]	[-.002 .162]	[-.111 .126]	[-.479 5.275]	[-.228 .406]	[-.213 .407]	[-.214 .542]	[-.254 .420]
Metals	.004	.013	-.014	.335[a]	.248*	.231a	.289	.403**
	[-.089 .095]	[-.063 .089]	[-.128 .100]	[-.142 8.231]	[-.030 .499]	[-.067 .472]	[-.127 .708]	[.023 .637]
Electric	-.046	-.006	-.052	-.105	.111	.167*	-.078	.254**
	[-.128 .036]	[-.076 .063]	[-.153 .050]	[-13.195 .360]	[-.178 .458]	[-.030 .540]	[-.678 .593]	[.036 .641]
Radio and TV	-.029	.011	-.001	.508	.594***	.621***	.486*	.603**
	[-.137 .078]	[-.077 .100]	[-.131 .128]	[-5.121 1.552]	[.191 1.177]	[.247 1.183]	[-.066 1.287]	[.126 1.223]
Other manufacturing	-.019	.013	-.016	.204	.014	-.045	.0002	.205
	[-.107 .069]	[-.060 .086]	[-.123 .092]	[-.332 9.556]	[-.280 .299]	[-.379 .217]	[-.391 .460]	[-.185 .433]
Telecoms	-	-	-	.920*	.580*	.520*	.888*	.602
				[-.055 14.543]	[-.072 1.262]	[-.084 1.08]	[-.221 2.095]	[-.101 1.226]
Data processing	-.066*	-.028	-.058	-.285	.079	.174*	-.199	.210**
	[-.140 .008]	[-.090 .033]	[-.150 .034]	[-17.328 .245]	[-.162 .390]	[-.029 .484]	[-.917 .552]	[.027 .605]
R&D	.007	.049	.024	.111	.-0.52	-.074	-.071	.096
	[-.073 .087]	[-.018 .117]	[-.075 .122]	[-.998 1.739]	[-.340 .224]	[-.286 .226]	[-.353 .251]	[-.184 .367]
Western Finland	.018	.026	.019	.304	.160**	.151**	.147*	.236***
	[-.028 .064]	[-.012 .065]	[-.038 .075]	[-.802 .770]	[.013 .342]	[.012 .328]	[-.011 .321]	[.079 .418]
Eastern Finland	.096**	.088**	.145***	-.262[a]	-.427***	-.374***	.539**	-.462***
	[.007 .185]	[.014 .162]	[.037 .252]	[-11.514 .172]	[-.644 -.128]	[-.548 -.059]	[-.980 -.030]	[-.622 -.094]
Central Finland/Oulu region	.069*	.031	.102**	.052	-.057	-.033	-.175	.062
	[-.006 .145]	[-.030 .092]	[.010 .193]	[-5.856 .547]	[-.291 .261]	[-.246 .255]	[-.600 .242]	[-.175 .369]
Northern Finland/Lapland	-.031	-.026	-.014	.194	.257	.280a	.245	.096
	[-.158 .095]	[-.121 .070]	[-.170 .142]	[-2.989 2.085]	[-.095 .715]	[-.027 .715]	[-.188 .702]	[-.190 .507]

NOTES: in the Tekes decision rule equations, we excluded the telecommunications dummy because of problems in the bootstrap that were due to the low proportion of telecommunications firms in our sample of firms with both Tekes evaluation grades. ***, **, *, and [a] denote significance at 1, 5, 10, and 15% level. Southern Finland is our base region.

A.5. Cross-validation

In the Table below, we present the cross-validation figures for the application and the investment equations. Cross-validation figures were calculated using equation (2.22) in Yatchew (1998).

Table A.5
Cross-validation of the Application and R&D Investment Equations

Specification	Application Equation	R&D Investment Equation
Linear term	0.0595	0.7961
+2nd power	0.0602	0.7982
+2nd and 3rd power	0.0586	0.8006
+2nd -4th power	0.0635	0.8039
+ 2nd and 3rd powers and 1st order interactions between continuous variables	0.0982	-

Notes: the linear term is the effect of expected subsidies on expected discounted profits in the application equation, and the propensity score transformation that DNV use (Mills ratio) in the R&D investment equation. The base specification is the same as in the ML estimations.